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Moens et al.

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(54) **METHOD OF FORMING A HIGH ELECTRON MOBILITY SEMICONDUCTOR DEVICE AND STRUCTURE THEREFOR**

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2924/12032 (2013.01); **H01L 2924/1305**
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29/66462; **H01L 29/66431**; **H01L 27/0605**
See application file for complete search history.

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(21) Appl. No.: **14/182,508**

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(65) **Prior Publication Data**

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H01L 29/66 (2006.01)
H01L 21/8252 (2006.01)
H01L 27/06 (2006.01)
H01L 29/20 (2006.01)

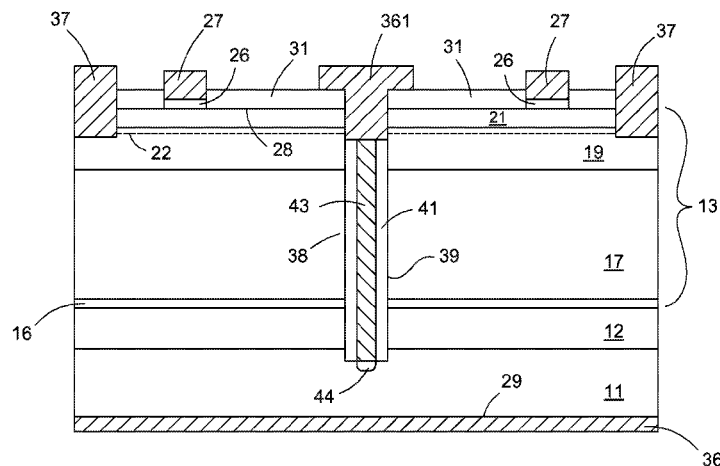
(57) **ABSTRACT**

In one embodiment, a method of forming a semiconductor device can comprise; forming a HEM device on a semiconductor substrate. The semiconductor substrate provides a current carrying electrode for the semiconductor device and one or more internal conductor structures provide a vertical current path between the semiconductor substrate and regions of the HEM device.

(52) **U.S. Cl.**

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20 Claims, 9 Drawing Sheets



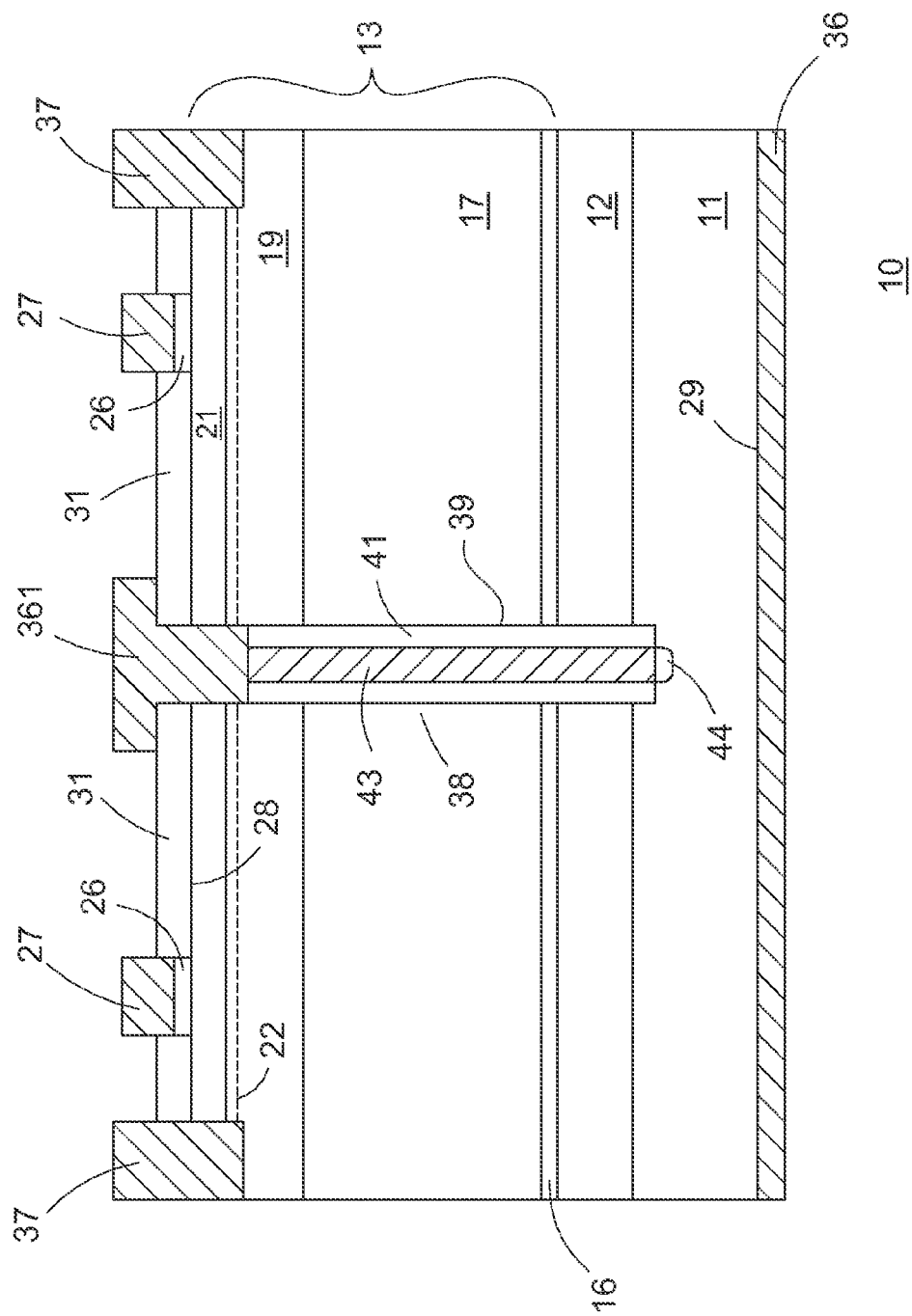


FIG. 1

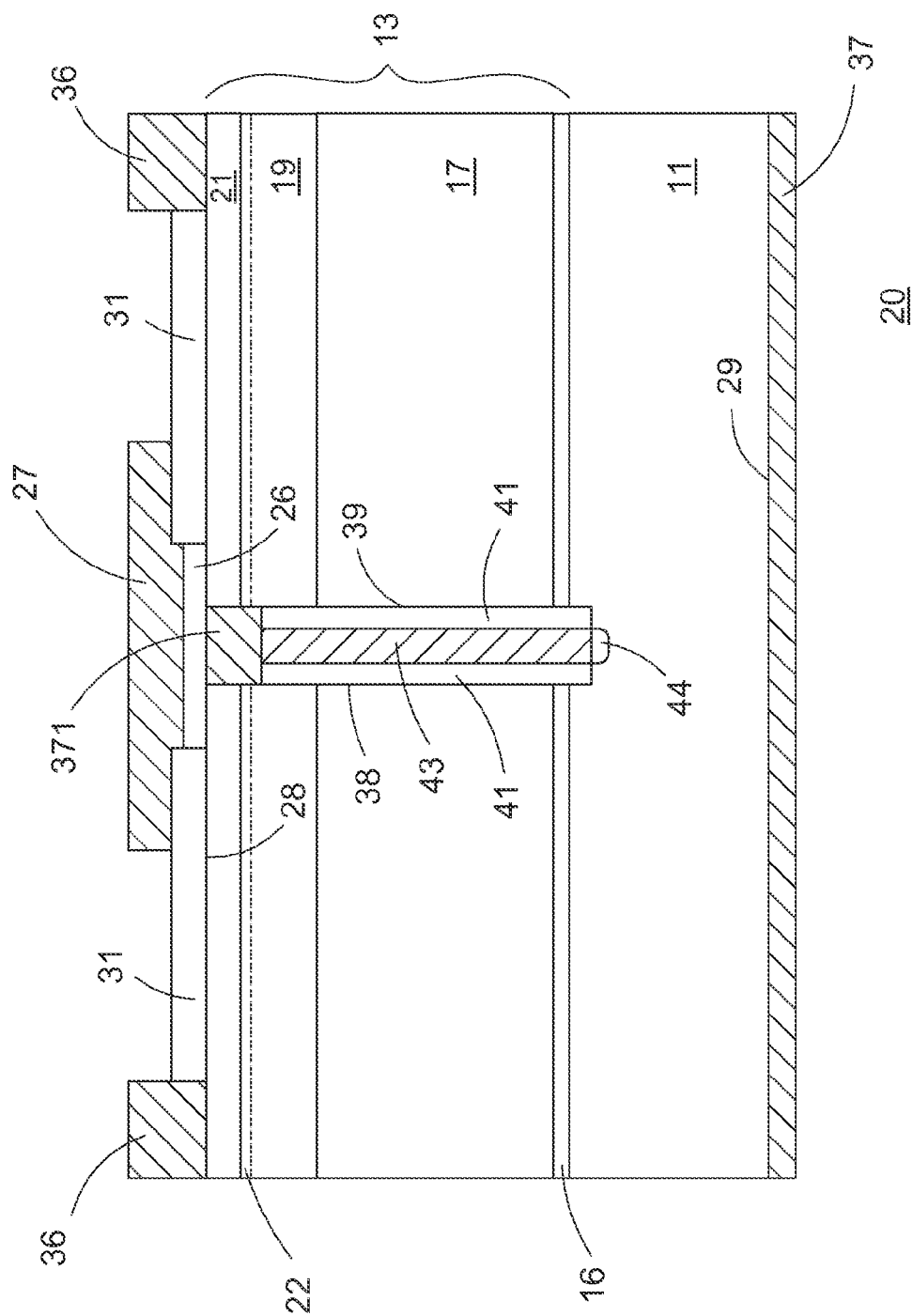


FIG. 2

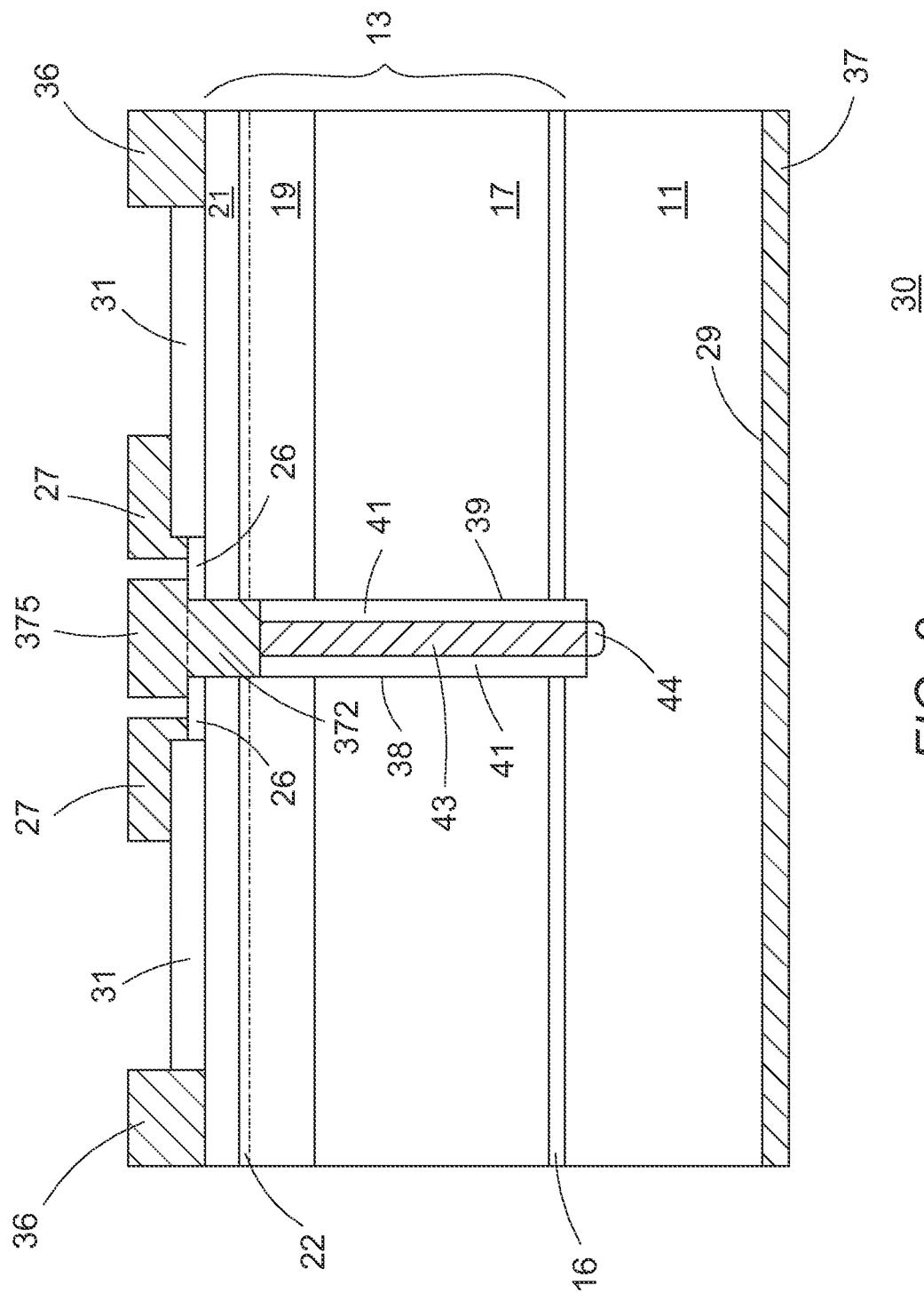


FIG. 3

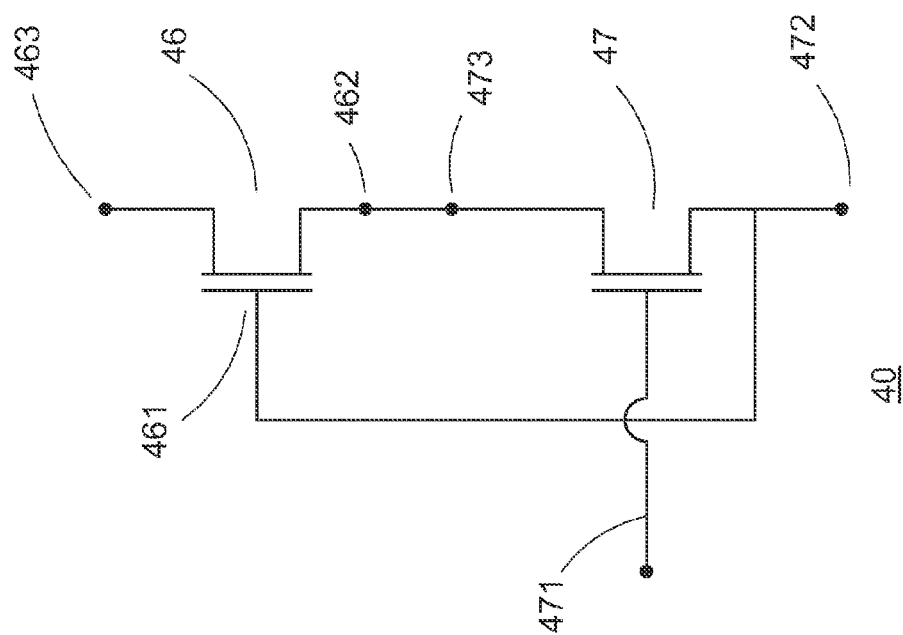


FIG. 4

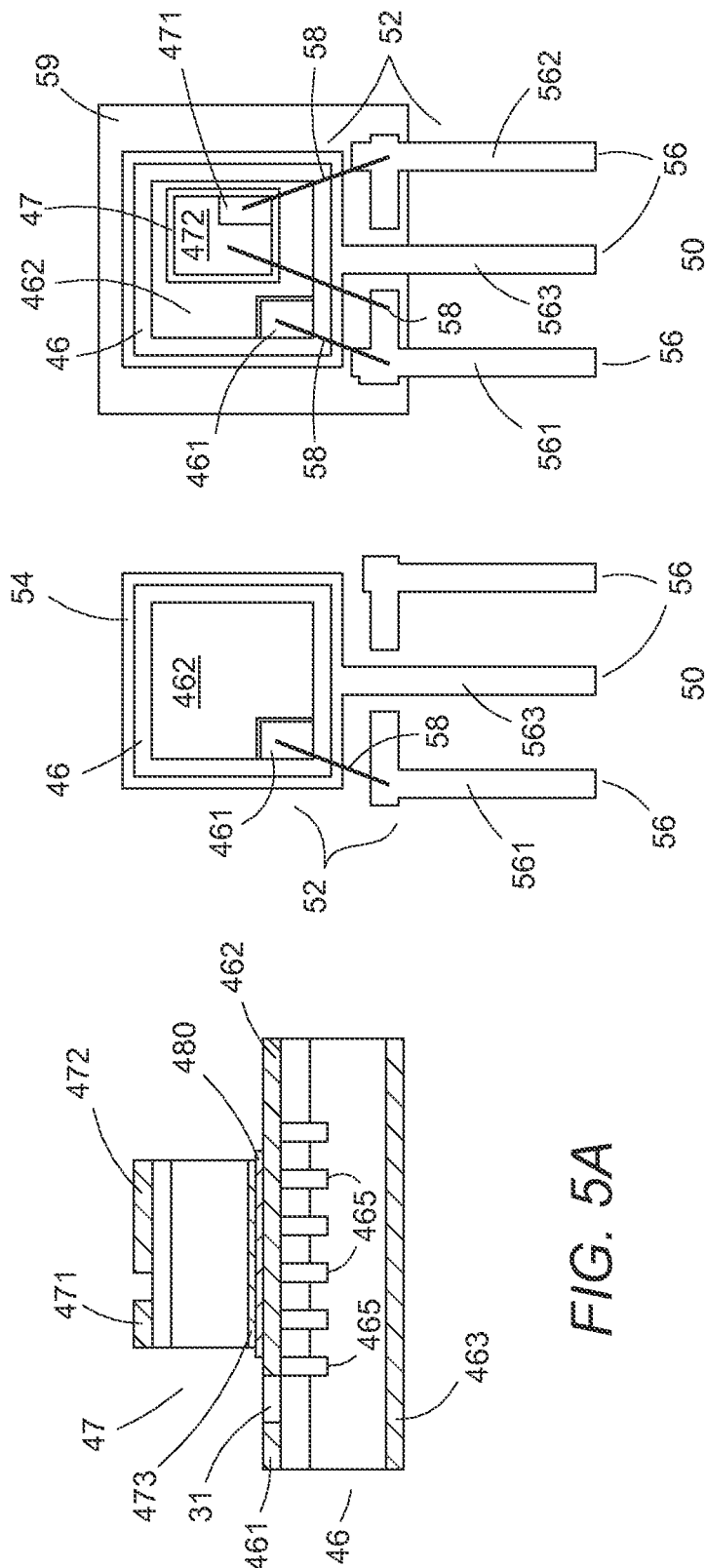
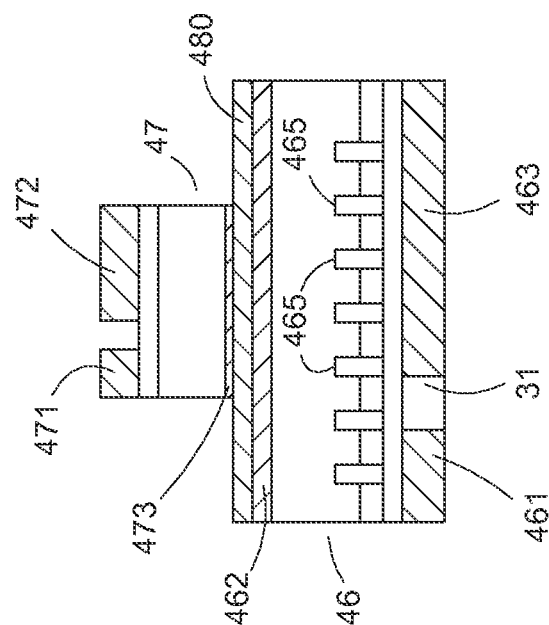
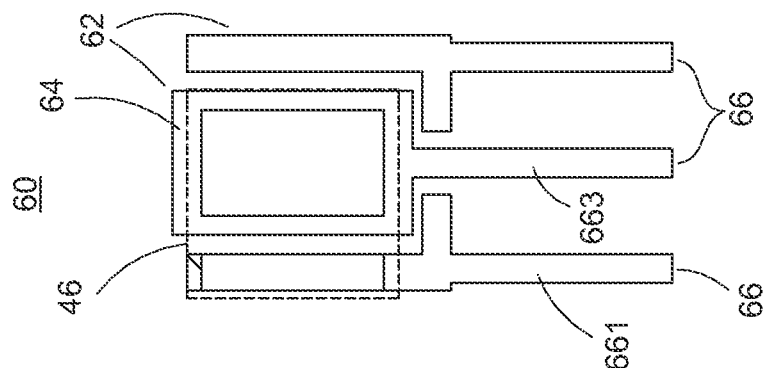
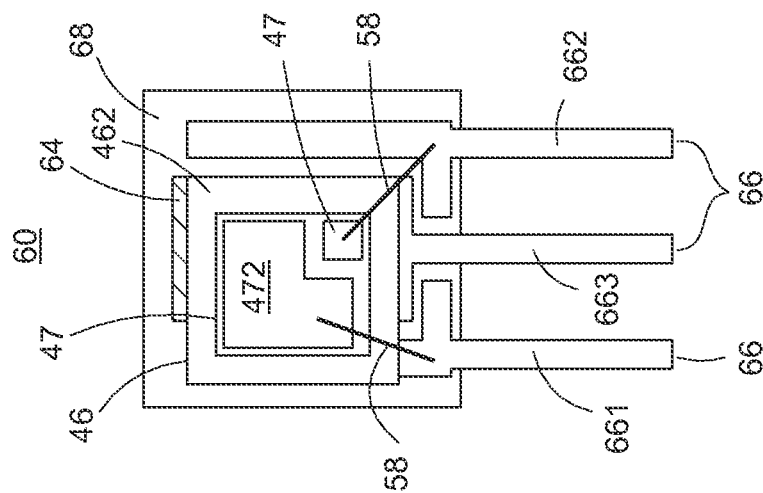
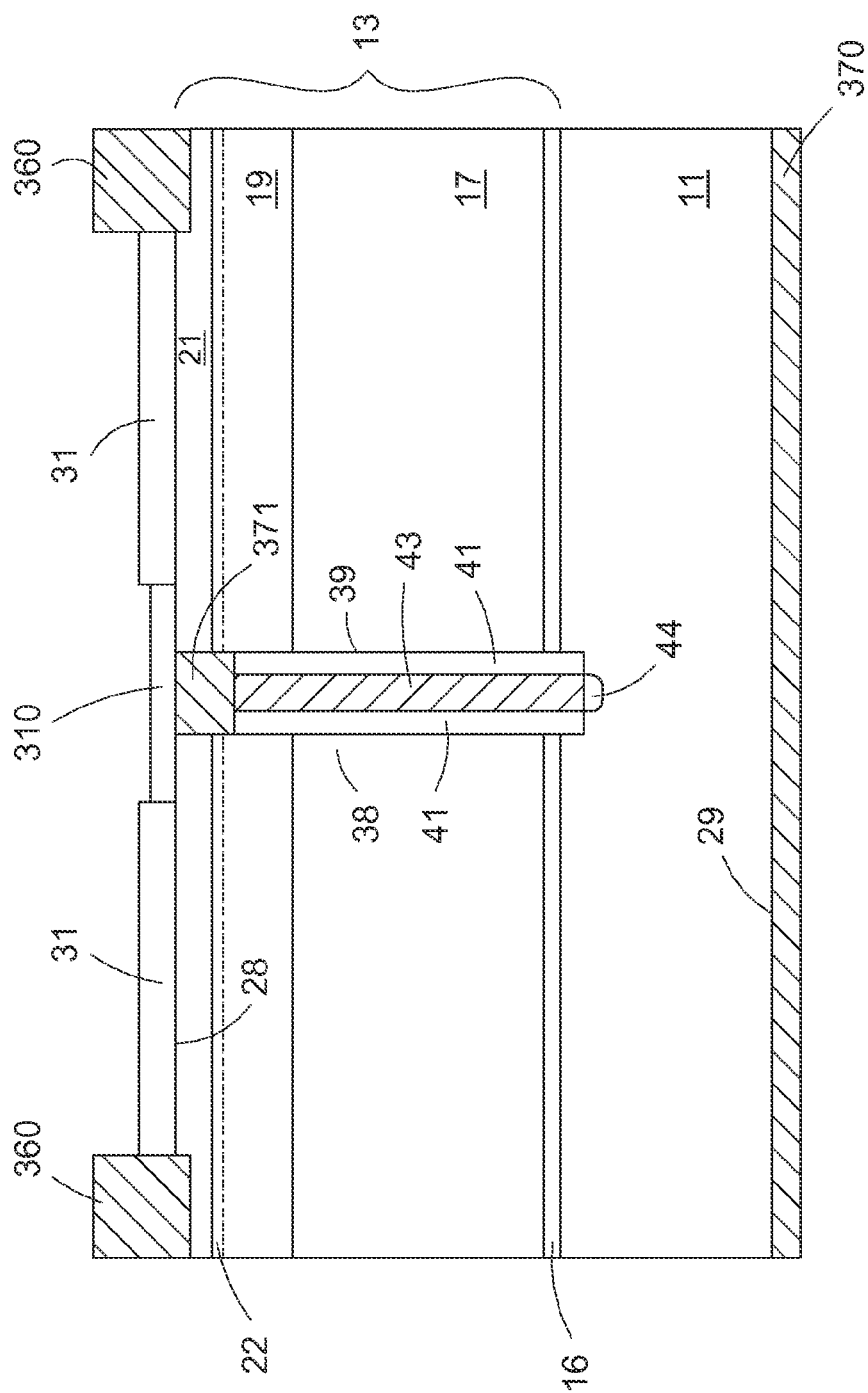


FIG. 5A

FIG. 5B

FIG. 5C





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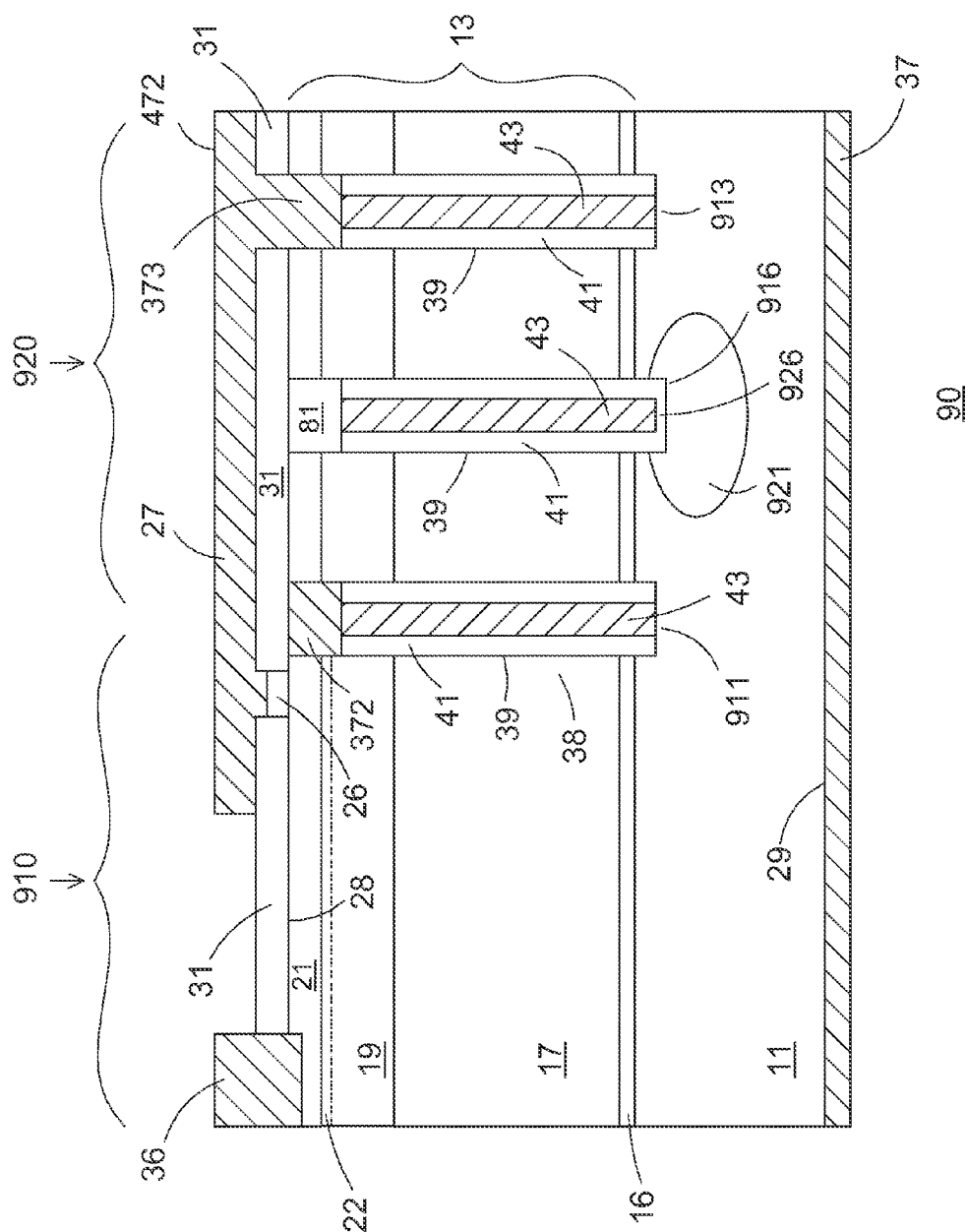


FIG. 8

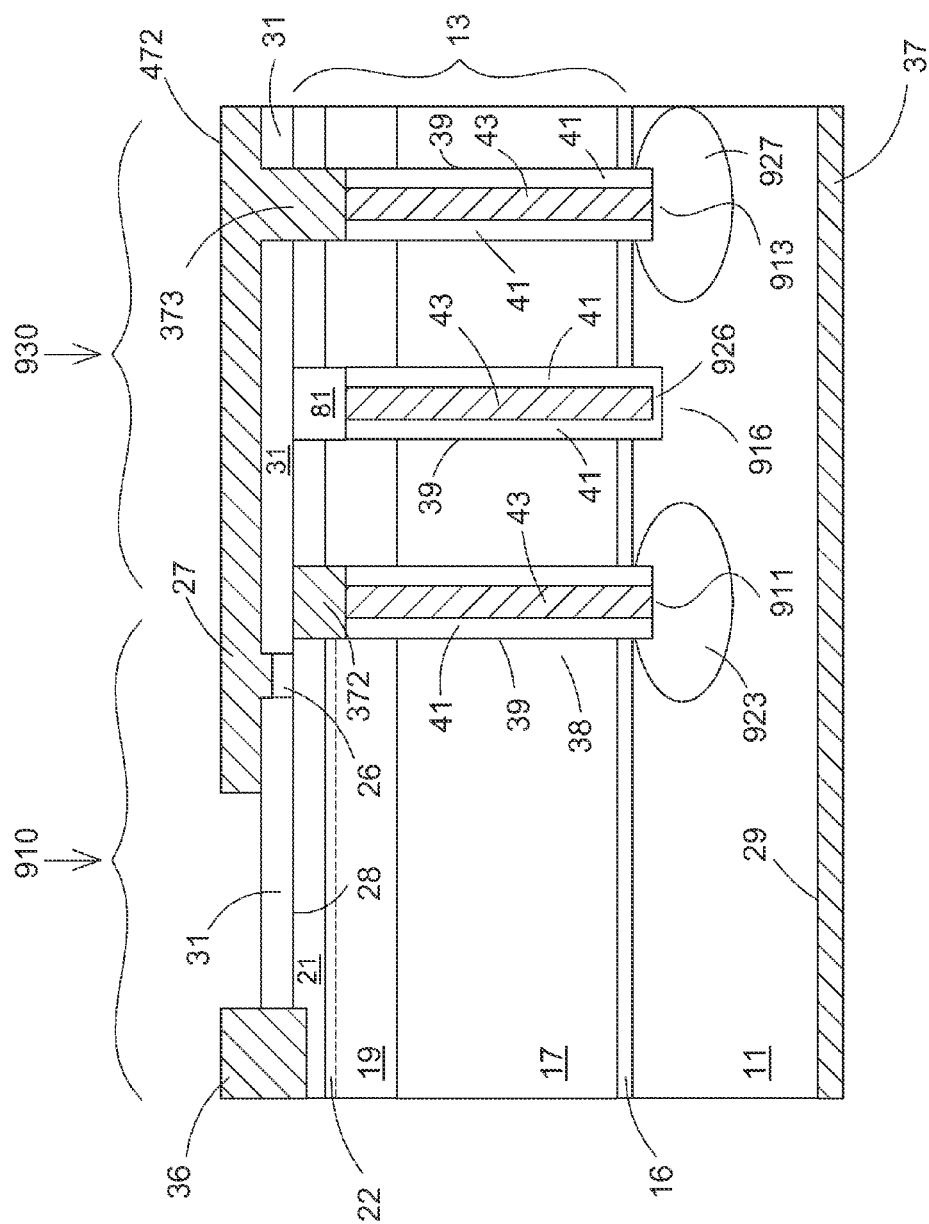


FIG. 9

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METHOD OF FORMING A HIGH ELECTRON MOBILITY SEMICONDUCTOR DEVICE AND STRUCTURE THEREFOR

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/786,596 filed Mar. 15, 2013.

BACKGROUND OF THE DISCLOSURE

The present invention relates, in general, to electronics, and more particularly, to semiconductors, structures thereof, and methods of forming semiconductor devices.

In the past, the semiconductor industry utilized various methods to form power semiconductor devices that used at least one III series semiconductor material, such as gallium nitride (GaN), as one of the semiconductor materials. Such power semiconductor devices were used in a variety of applications including power supplies and motor controllers including high voltage switching circuits. GaN power semiconductor devices built on silicon substrates, such as high electron mobility transistor ("HEMT") devices, have been lateral devices with both the source and drain electrodes on the top surface of the device. However, this configuration made it difficult to form connections to various portions of the semiconductor devices. It also was difficult to package the GaN devices with silicon metal-oxide-semiconductor (MOS) transistors.

Accordingly, it is desirable to have a semiconductor device using GaN or other III series materials such as a III-nitride series material or SiC that has improved device connectability as well as integration capability.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an enlarged cross-sectional view of an embodiment of a depletion mode semiconductor device in accordance with the present invention;

FIG. 2 illustrates an enlarged cross-sectional view of an embodiment of an enhancement mode semiconductor device in accordance with another embodiment of the present invention;

FIG. 3 illustrates an enlarged cross-sectional view of a depletion mode semiconductor device that is an alternate embodiment of the semiconductor device of FIG. 2;

FIG. 4 schematically illustrates a cascode circuit configuration in accordance with the present invention;

FIG. 5A illustrates an enlarged cross-sectional view of a HEMT device and a MOSFET device in a cascode configuration in accordance with an embodiment of the present invention;

FIGS. 5B and 5C illustrate top views of a packaged semiconductor device including the embodiment of FIG. 5A at various stages of fabrication;

FIG. 6A illustrates an enlarged cross-section view of a HEMT device and a MOSFET device in a cascode configuration in accordance with another embodiment of the present invention;

FIGS. 6B and 6C illustrate top views of a packaged semiconductor device including the embodiment of FIG. 6A at various stages of fabrication;

FIG. 7 illustrates an enlarged cross-sectional view of an embodiment of a Schottky diode structure in accordance with the present invention;

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FIG. 8 illustrates an enlarged cross-sectional view of an embodiment of a multi-transistor device that includes a depletion mode HEMT and a silicon MOSFET formed monolithically on one semiconductor substrate in accordance with the present invention; and

FIG. 9 illustrates an enlarged cross-sectional view of another embodiment of a multi-transistor device in accordance with another embodiment of the present invention.

For simplicity and clarity of the illustration(s), elements in the figures are not necessarily to scale, and the same reference numbers in different figures denote the same elements, unless stated otherwise. Additionally, descriptions and details of well-known steps and elements are omitted for simplicity of the description. As used herein current carrying electrode means an element of a device that carries current through the device such as a source or a drain of a MOS transistor or an emitter or a collector of a bipolar transistor or a cathode or anode of a diode, and a control electrode means an element of the device that controls current through the device such as a gate of a MOS transistor or a base of a bipolar transistor. Although the devices are explained herein as certain N-channel or P-Channel devices, or certain N-type or P-type doped regions, a person of ordinary skill in the art will appreciate that complementary devices are also possible in accordance with the present invention. One of ordinary skill in the art understands that the conductivity type refers to the mechanism through which conduction occurs such as through conduction of holes or electrons, therefore, and that conductivity type does not refer to the doping concentration but the doping type, such as P-type or N-type. It will be appreciated by those skilled in the art that the words during, while, and when as used herein relating to circuit operation are not exact terms that mean an action takes place instantly upon an initiating action but that there can be some small but reasonable delay (s), such as various propagation delays, between the reaction that is initiated by the initial action. Additionally, the term while means that a certain action occurs at least within some portion of a duration of the initiating action. The use of the word approximately or substantially means that a value of an element has a parameter that is expected to be close to a stated value or position. However, as is well known in the art there are always minor variances that prevent the values or positions from being exactly as stated. It is well established in the art that variances of up to at least ten per cent (10%) (and up to twenty per cent (20%) for semiconductor doping concentrations) are reasonable variances from the ideal goal of exactly as described. The terms first, second, third and the like in the claims or/and in the Detailed Description of the Drawings, as used in a portion of a name of an element are used for distinguishing between similar elements and not necessarily for describing a sequence, either temporally, spatially, in ranking or in any other manner. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments described herein are capable of operation in other sequences than described or illustrated herein. For clarity of the drawings, doped regions of device structures are illustrated as having generally straight line edges and precise angular corners. However, those skilled in the art understand that due to the diffusion and activation of dopants the edges of doped regions generally may not be straight lines and the corners may not be precise angles.

In addition, the description may illustrate a cellular design (where the body regions are a plurality of cellular regions) instead of a single body design (where the body region is comprised of a single region formed in an elongated pattern, typically in a serpentine pattern). However, it is intended that

the description is applicable to both a cellular implementation and a single base implementation.

DETAILED DESCRIPTION OF THE DRAWINGS

In general, the present embodiments relate to a structure and a method of forming the structure for high electron mobility ("HEM") devices. The HEM devices include a base semiconductor substrate and a heterostructure associated with the base substrate. In some embodiments, the heterostructure is a III-nitride series material such as gallium nitride (GaN), aluminum gallium nitride (AlGa_N), indium nitride (InN), aluminum nitride (AlN), indium gallium nitride (InGa_N), indium aluminum gallium nitride (InAlGa_N), or similar materials as known to those of skill in the art. The base semiconductor substrate provides a first current carrying electrode for the HEM device. In some embodiments, a gate structure is provided adjacent a major surface of the heterostructure and a second current carrying electrode is on the major surface but spaced apart from the gate structure.

In some embodiments, the heterostructure includes a GaN channel layer and an AlGa_N barrier layer. In some embodiments, at least one internal connector structure extends through the heterostructure to the base semiconductor substrate to provide a low resistance electrical current path from the base substrate to regions of the device proximate to the barrier layer. In some embodiments, the internal connector structure can include first and second conductors. In some embodiments, the internal connector structure includes at least one trench formed in the heterostructure and a portion of the base semiconductor substrate. In some embodiments, the trench is lined with an insulating material and further lined or filled with a conductive material adjacent the insulating material. In other embodiments, the HEM device is integrated with a MOSFET device in a monolithic single-chip configuration.

Attributes of the method and structure described hereinafter provide for the routing of source and gate conductive lines on the top surface of a die with the drain conductive layer on the back surface of the die. In some embodiments, both the source and gate terminals are biased at low voltage, which puts a lower stress on inter-metal dielectric structures. This lower stress reduces electro-migration issues. The structure also provides for semiconductor chip area savings of at least 30% because bonding to the source and gate terminals can be done over the active area of the device. Additionally, the configuration facilitates the assembly of the HEM devices with other devices such as silicon MOSFET devices, which reduces parasitic inductances and resistances compared to related devices.

FIG. 1 illustrates an enlarged cross-sectional view of an embodiment of a semiconductor device **10** configured as a III-nitride depletion mode high electron mobility transistor ("HEMT"). Transistor **10** includes a base substrate, base semiconductor substrate, a region of semiconductor material, semiconductor region, or semiconductor substrate **11**. In several embodiments, substrate **11** is a silicon substrate having a (111) orientation and is doped with an n-type dopant such as phosphorous, arsenic or antimony. In other embodiments, substrate **11** can have other orientations. In other embodiments, substrate **11** can be silicon-carbide or other semiconductor materials that can be doped to form a current carrying electrode. In several embodiments, substrate **11** has a low resistivity (that is, has a high dopant concentration) with a resistivity in a typical range from about 0.001 to about 0.01 ohm-cm. In the present embodiment, transistor **10** also includes an optional field extension layer **12**, which can be a lower doped n-type silicon epitaxial layer. In other embodi-

ments, field extension layer **12** can be lower doped p-type conductivity. The thickness of field extension layer **12** depends on the required blocking voltage of transistor **10** and a typical thickness is in a range from 2 microns to about 20 microns.

Transistor **10** also includes a heterostructure or epitaxial structure **13**, which can be formed on substrate **11** or field extension layer **12** if field extension layer **12** is included. In several embodiments, heterostructure **13** includes a plurality of layers including, for example, a nucleation or buffer layer **16**, one or more buffer or transition layers **17**, a channel layer **19**, and a barrier layer **21**. In some embodiments, buffer layer **16** can be, for example, an MN layer situated over field extension layer **12**. One or more transition layers **17**, which can be optional in some embodiments, can be formed situated over buffer layer **16**. In some embodiments, transition layers **17** can be, for example, AlGa_N with varying amounts of aluminum concentration. For example, the aluminum concentration can be higher in the transition layers **17** closer to buffer layer **16** and lower closer to channel layer **19**.

Channel layer **19** can be formed situated over buffer layer **16** or optional transition layers **17**. In several embodiments, channel layer **19** can be, for example, a GaN layer. In some embodiments, barrier layer **21** can be AlGa_N and formed over channel layer **19**. At the interface of the AlGa_N layer **21** and the GaN channel **19** a two-dimensional electron gas (2DEG) layer or region **22** is created, as known to those of ordinary skill in the art.

In some embodiments, transistor **10** further includes a gate dielectric layer or region **26** situated over a portion of barrier layer **21** as illustrated in FIG. 1. In other embodiments, transistor **10** can be configured with a Schottky gate. In some embodiments, gate dielectric region **26** can be silicon nitride, aluminum nitride, aluminum oxide, silicon dioxide or combinations thereof, hafnium oxide, or other materials as known to those of ordinary skill in the art. A control or gate electrode **27** is situated over gate dielectric region **26**, and can be, for example, aluminum with a titanium and/or titanium-nitride barrier or other conductive materials as known to those of ordinary skill in the art. As illustrated in FIG. 1, transistor **10** can also include an insulation or insulative layer or layers **31** situated over portions of major surface **28** of heterostructure **13**, which can be, for example, silicon nitride, aluminum nitride, combinations thereof, or other insulative materials as known to those of ordinary skill in the art. In some embodiments, insulation layer **31** can be silicon nitride formed using plasma-enhanced chemical vapor deposition techniques ("PECVD"), low pressure chemical vapor deposition ("LPCVD"), metal organic chemical vapor deposition ("MOCVD"), or atomic layer deposition ("ALD"), and can have a thickness in some embodiments from about 0.1 microns to about 0.2 microns. In some embodiments, the silicon nitride forms a field plate that reduces the effect of the high electric fields that can be formed between the drain and gate regions.

In the present embodiment, source electrodes **37** are situated over major surface **28** and contacting barrier layer **21** making ohmic contact to 2DEG region **22**. In accordance with the present embodiment, gate electrode **27** can include a Schottky barrier material at the connection with 2DEG region **22**. By way of example, titanium-tungsten (with an optional a titanium nitride barrier layer) can be used to form the Schottky barrier. In some embodiments, source electrodes **37** can further include aluminum with a barrier layer such as titanium and/or titanium nitride or other conductive materials as known to those of ordinary skill in the art to provide ohmic contacts.

In accordance with the present embodiment, a drain electrode **36** is formed situated adjacent major surface **29** of substrate **11**, which is opposite to major surface **28**. In some embodiments, drain electrode **36** can be referred to as a drain-down configuration. In several embodiments, drain electrode **36** can be a laminated structure of titanium-nickel-silver, chrome-nickel-gold, or other conductive materials as known to those of ordinary skill in the art.

Also, transistor **10** includes one or more internal conductor structures **38**. In several embodiments, internal conductor structures **38** each include a trench **39** formed to extend from major surface **28** generally downward and extending through heterostructure **13**, field extension layer **12**, and into substrate **11**. Trench **39** can be formed using photolithographic techniques and wet or dry etching techniques. In some embodiments, trench **39** is lined or covered with an insulating material or layer **41**. Insulating layer **41** can be, for example, silicon oxide, silicon nitride, aluminum oxide, aluminum nitride, or other materials as known to those of ordinary skill in the art. Insulating layer **41** can be formed using PECVD techniques and/or atomic level deposition (ALD) techniques. In one embodiment, insulating layer **41** is aluminum nitride deposited using ALD techniques. In accordance with the present embodiment, insulating layer **41** is configured to help isolate substrate **11**, field extension layer **12**, and heterostructure **13** from high voltage drain potential when transistor **10** is in operation. Also, insulating layer **41** advantageously prevents or reduces the inversion electrons in the Si—GaN interface from leaking away (for example, to a die edge). This provides the necessary charge to effectively build-up an extra depletion layer in substrate **11**, which advantageously increases breakdown voltage.

Insulating layer **41** is locally etched at the bottom surface of trench **39** to form an opening that exposes a portion of substrate **11**. Photolithographic and etch techniques are example techniques used for forming the opening adjoining the bottom surface of trench **39**. In some embodiments, insulating layer **41** is further recessed or removed from upper surfaces of trench **39** to a location proximate to or slightly below 2DEG region **22** as illustrated in FIG. 1. In other embodiments, an optional enhancement region **44** can be formed situated adjoining a lower surface of trench contact **43** in substrate **11**. By way of example, enhancement region **44** can be a doped region or can be a silicide region.

In some embodiments, a conductive material is formed within trench **39** adjoining insulating layer **41** and contacting substrate **11** through the opening in the bottom of trench **39** to form a conductive trench contact or second conductor **43**. In some embodiments, trench contact **43** can be, for example, doped polycrystalline semiconductor material, doped polysilicon, aluminum, copper, tungsten, or other similar materials as known to those of ordinary skill in the art. In some embodiments, the conductive layer is deposited over the structure and within trench **39**, and then planarized and recessed within trench **39** to form trench contact **43** as illustrated in FIG. 1. Another conductive material can then be deposited over major surface **28** and patterned to leave a first conductor or ohmic contact **361** adjacent to major surface **28** and contacting 2DEG region **22** and trench contact **43**. In some embodiments, first conductor **361** can be aluminum with a barrier layer such as titanium and/or titanium nitride or other conductive materials as known to those of ordinary skill in the art.

In accordance with the present embodiment, a main current carrying electrode or terminal is advantageously placed at the backside (that is, the major surface opposite to the surface where another main current carrying electrode is placed) of

substrate **11** where it is contacted by electrode **36**. More particularly, the transistor of the present embodiment has a lateral current conductive component between source contact **37** and first conductor **361** through 2DEG region **22**. In the present structure, gate pinch-off can have a lateral orientation. The current is then picked up by trench electrode **43** as a vertical current conductive component to substrate **11** and drain electrode **36**. In some embodiments, it is contemplated that trench contact **43** is placed under each first conductor **361** within transistor **10**, and directly brought down to substrate **11** and in electrical communication with drain electrode **36** thereby eliminating the need for lateral metal routing over major surface **28**. This approach reduces electro-migration issues associated with power metal routing lines or traces.

As will be explained in more detail later, the present embodiment is advantageously configured to accommodate the integration of a silicon MOSFET in, for example, a stacked die configuration, which reduces parasitic inductances and resistances and further facilitates a simplified assembly process. A further advantage of the present embodiment is that with drain electrode **36** on the backside of substrate **11**, there is no high voltage metal routing on the front side of transistor **10**, which facilitates the placement of the source electrode pad overlying the active region of transistor **10**. This provides a chip area savings of at least 30%.

Referring now to FIG. 2, there is illustrated a semiconductor device **20** in accordance with another embodiment. Transistor **20** can be referred to as a HEMT device because of the high mobility of electrons in channel layer **19**. In some embodiments, transistor **20** is configured as an enhancement mode device. Transistor **20** is similar in structure to the previously described transistor **10**, with only the distinctions between the transistors **10**, **20** described hereinafter.

One distinction between transistors **10**, **20** is the placement of source electrode **37** on major surface **29** and the placement of drain electrodes **36** on major surface **28** to provide what is referred to as a source down configuration. In some embodiments, drain electrodes **36** provide ohmic contacts to barrier layer **21**. In other embodiments, drain electrodes **36** provide ohmic contacts to 2DEG region **22**. Another distinction between transistors **10**, **20** is the configuration of the gate structure, which is formed in transistor **20** on barrier layer **21** between drain electrodes **36**. In the present embodiment, gate layer **26** can be hafnium dioxide or aluminum oxide or other materials as known to those of ordinary skill in the art. In the present embodiment, the gate structure depletes some of the charge in the gate channel and assists in forming the enhancement mode characteristics of transistor **20**. A further distinction between transistors **10**, **20** is that internal vertical connector structure **38** is formed through channel layer **19** to form a low resistance electrical connection between the source region of substrate **11** and barrier layer **21**. The internal connector structure **38** includes a first conductor **371** formed in contact with barrier layer **21**. First conductor **371** forms an electrical connection to the material of barrier layer **21**. Typically, at least a portion of first conductor **371** abuts a portion of barrier layer **21**. In some embodiments, first conductor **371** is recessed within barrier layer **21**. In other embodiments, first conductor **371** can extend through barrier layer **21** to major surface **28** as illustrated in FIG. 2. In another embodiment, first conductor **371** forms a Schottky contact. The Schottky contact can also assist in the enhancement mode characteristics of some embodiments. In another embodiment, first conductor **371** can underlie gate layer **26**, but can be in other positions in other embodiments. First conductor **371** can be

formed from polysilicon, doped polysilicon, tungsten, aluminum, or other conductor materials as known to those of skill in the art.

Isolation layer 31 is formed to be situated on a portion of barrier layer 21 between drain electrodes 36 and the gate structure and can extend partially under a portion of gate electrode 27. In some embodiments, insulator layer 31 forms a field plate that reduces the effect of high electric fields that can be formed between the drain and gate structure when transistor 20 is in operation. Similar to transistor 10, transistor 20 includes low resistance trench contact 43, which improves the operation of transistor 20.

FIG. 3 illustrates an enlarged cross-sectional view of a depletion mode semiconductor device 30 that is an alternate embodiment of transistor 20. Transistor 30 can be sometimes referred to as a HEMT device because of the high mobility of electrons in channel layer 19. Transistor 30 is similar in structure to the previously described transistor 20, with only the distinctions between the transistors 20, 30 described hereinafter. One distinction between transistors 20, 30 is the first conductor of internal conductor structure 38 can be extended through gate layer 26 and form an overhang 375 on dielectric layer 26. Gate electrode 27 is spaced apart from overhang 375 by at least 0.1 μm . In another embodiment, overhang 375 can be made out of the same metal layer as gate electrode 27.

FIG. 4 schematically illustrates a cascode circuit configuration 40 of a depletion mode HEMT device 46 and a metal oxide semiconductor field effect transistor (MOSFET) 47 in accordance with one embodiment. HEMT device 46 includes a gate electrode 461, a source electrode 462, and a drain electrode 463. MOSFET 47 includes a gate electrode 471, a source electrode 472 electrically connected to gate electrode 461 of HEMT device 46, and a drain electrode 473 electrically connected to source electrode 462 of HEMT device 46. In some embodiments, depletion mode HEMT device 46 can be a 60 m Ω 600V HEMT and MOSFET 47 can be a 20 m Ω 20V silicon MOSFET. In some embodiments of configuration 40, the threshold voltage (V_{th}) is determined by V_{th} of MOSFET 47. For the gate ON condition, gate electrode 461 and source electrode 462 of HEMT device 46 are at zero volts. Because of the depletion mode characteristics, the depletion mode transistor is ON. For the gate OFF condition, gate electrode 461 of HEMT device 46 is about 10-20V below source (determined by leakage current in HEMT device 46). Because of the depletion mode characteristics, the depletion mode transistor is OFF. At least some of the embodiments of the HEM transistors presented herein provide an improved structure for achieving a simplified cascode stacking of a silicon MOSFET with a III-nitride depletion mode HEMT device. One attribute of this structure is that it provides enhancement mode emulation with reduced parasitic inductance between the drain of the silicon MOSFET and the source of the HEMT. Among other things, this reduces ringing effects.

FIGS. 5A-C and 6A-C are simplified cross-sectional views of stacked MOSFET and HEMT devices and top views of the stacked devices on example lead frame structures to illustrate embodiments of cascode configuration 40. FIG. 5A illustrates a MOSFET 47 stacked onto a depletion mode HEMT device 46 in accordance with a first embodiment. In this embodiment, HEMT device 46 is a drain down configuration and can be, for example, similar to transistor 10. HEMT device 46 includes drain electrode 463, which is in electrical communication with vertical internal conductor structures 465 described previously. On the opposite surface, source electrode 462 is separated from gate electrode 461 by insulative layer 31 described previously. In some embodiments, MOS-

FET 47 is attached to source electrode 462 using a conductive attach structure 480, which can be, for example, a conductive solder or epoxy or other materials. In this configuration, drain electrode 473 of MOSFET 47 is attached to source electrode 462 of HEMT device 46. It is understood that some of the details of HEMT device 46 discussed previously in conjunction with transistor 10 may not be shown in FIG. 5A to simply the illustration.

FIG. 5B is a top view of a packaged semiconductor device 50 at an intermediate stage of fabrication. In some embodiments, device 50 has a lead frame 52 that includes a die pad 54 and a plurality of leads 56. It is understood that device 50 can use other types of package substrates. At this stage of fabrication, drain electrode 463 of HEMT device 46 is attached with a conductive material (not shown) to die pad 54. Gate electrode 461 is electrically connected to one of the leads 56 configured as a gate lead 561. In some embodiments, gate electrode 461 is connected to gate lead 561 with a conductive wire 58. One of leads 56 is configured as a drain lead 563 and in some embodiments is directly connected to die pad 54 as illustrated in FIG. 5B. Element 462 is the source electrode, which is sized and configured to facilitate the placement of MOSFET 47 in contact with it.

FIG. 5C is a top view of packaged semiconductor device 50 after additional processing that includes attaching MOSFET 47 to source electrode 462 of HEMT device 46 with conductive attach structure 480 (illustrated in FIG. 5A). Source electrode 472 of MOSFET 47 is electrically connected to gate lead 561 with, for example, another conductive wire 58. Gate electrode 471 of MOSFET 47 is electrically connected to another lead 56 configured as another gate lead 562 with, for example, a further conductive wire 58. Packaged semiconductor device 50 can then be encapsulated with a molded resin material 59 to protect the structure. Packaged semiconductor device 50 is an embodiment of a cascode transistor configuration 40 illustrated in FIG. 4 that is facilitated by HEMT device 46 having a drain down configuration in accordance with at least one of the present embodiments.

FIG. 6A illustrates a MOSFET 47 stacked onto a depletion mode HEMT device 46 in accordance with another embodiment. In this embodiment, HEMT device 46 is a source down configuration and can be, for example, similar to transistor 30. HEMT device 46 includes source electrode 462, which is in electrical communication with vertical internal conductor structures 465 described previously. On the opposite surface, drain electrode 463 is separated from gate electrode 461 by insulative layer 31 described previously. In some embodiments, MOSFET 47 is attached to source electrode 462 using a conductive attach structure 480, which can be, for example, a conductive solder or epoxy or other materials. In this configuration, drain electrode 473 of MOSFET 47 is attached to source electrode 462 of HEMT device 46. It is understood that some of the details of HEMT device 46 discussed previously in conjunction with transistor 30 may not be shown in FIG. 6A to simply the illustration.

FIG. 6B is a top view of a packaged semiconductor device 60 at an intermediate stage of fabrication. In some embodiments, device 60 has a lead frame 62 with a die pad 64 and plurality of leads 66. It is understood that device 60 can use other types of package substrates. At this stage of fabrication, drain electrode 463 of HEMT device 46 is attached with a conductive material (not shown) to die pad 64 and gate electrode 461 is attached with a conductive material to one leads 66 configured as a gate lead 661. In some embodiments, HEMT device 46 can be attached with a conductive solder, a conductive epoxy or similar material. The outline of HEMT device 46 is shown as a dashed line to illustrate the direct

attachment of gate electrode **461** and drain electrode directly lead frame **62**. One of leads **66** is configured as a drain lead **663** and in some embodiments is directly connected to die pad **64** as illustrated in FIG. **6B**.

FIG. **6C** is a top view of packaged semiconductor device **60** after additional processing that includes attaching MOSFET **47** to source electrode **462** of HEMT device **46** with conductive attach structure **480** (not shown). Source electrode **472** of MOSFET **47** is electrically connected to gate lead **661** with, for example, another conductive wire **58**. Gate electrode **471** of MOSFET **47** is electrically connected to another lead **66** configured as another gate lead **662** with, for example, a further conductive wire **58**. Packaged semiconductor device **60** can then be encapsulated with a molded resin material **68** to protect the structure. Packaged semiconductor device **60** is an embodiment of a cascode transistor configuration **40** illustrated in FIG. **4** that is facilitated by HEMT device **46** having a source down configuration in accordance with the present embodiments.

FIG. **7** illustrates an enlarged cross-sectional view of an embodiment of a Schottky diode **70**. Diode **70** is similar in structure to transistor **20** (FIG. **2**), with only the distinctions between the transistor **20** and diode **70** described hereinafter. One distinction between transistor **20** and diode **70** is gate layer **26** and gate electrode **27** are omitted. In addition, another insulative layer **310** overlies first conductor **371** of the internal conductor structure. Insulative layer **310** can be a similar material to insulative layer **31**. In some embodiments, insulative layer **310** can be silicon nitride. In some embodiments, electrodes **360** are configured as anode electrodes for diode **70** and electrode **370** is configured as a cathode electrode for diode **70**. Electrodes **360** and **370** can be similar materials as described previously for electrodes **36** and **37**. Electrode **360** makes a Schottky contact to 2DEG region **22**, whereas electrode **371** makes an ohmic contact to 2DEG region **22**. In accordance with the present embodiment, internal conductor structure **38** provides a vertical conduction path between the anodes and cathode of diode **70**. This configuration is referred to as "cathode-down". In yet another embodiment, referred to as "anode-down", electrode **360** makes an ohmic contact to 2DEG region **22**, whereas electrode **371** makes a Schottky contact to 2DEG region **22**. Internal conductor structure **38** provides a vertical conduction path between the anode and cathodes of diode **70**.

FIG. **8** illustrates an enlarged cross-sectional view of an embodiment of a multi-transistor device **90** that includes a depletion mode HEMT device **910** and a silicon MOSFET **920** formed together in a cascode circuit configuration monolithically on one semiconductor substrate resulting in a monolithically integrated semiconductor device. In some embodiments, the one semiconductor substrate includes substrate **11** having heterostructure **13** or substrate **11** with layer **12** and having heterostructure **13** as described previously.

Device **90** includes a depletion mode HEMT transistor **910** that can be configured similarly to transistor **30**. In another embodiment, substrate **11** of device **90** can have a different doping concentration, for example a lower dopant concentration, than that of substrate **11** of transistor **30**. Substrate **11** forms the source of HEMT device **910** and a drain of HEMT device **910** is formed on surface **28** of device **90** similarly to transistor **30**. Gate layer **26** underlies at least one portion of gate electrode or conductor **27** of HEMT device **910**. The drain of the HEMT is contact **36**. In region **920** of device **90**, the 2DEG region **22** is destroyed, for example, by ion implantation with nitrogen, argon, iron, or similar methods as known to those of ordinary skill in the art. In region **910** (HEMT device) of device **90**, the 2DEG region **22** is maintained.

A first internal conductor structure **911** forms a low resistance connection to and between 2DEG region **22** (and hence the drain region of MOSFET device **920**) and substrate **11**. In some embodiments, first internal conductor structure **911** is similar to internal conductor structure **38** and includes a trench **39** extending from major surface **28** into substrate **11**. Similar to transistor **30**, trench **39** is lined with insulating layer **41** and further includes a conductive trench contact **43** configured to provide an ohmic contact to substrate **11**. In some embodiments, first internal conductor structure **911** is electrically connected to 2DEG region **22** through first conductor **372**, which forms an electrical connection to trench contact **43**. Conductor **372** is isolated from gate electrode **27** through insulating layer **31**.

A second internal conductor structure **913** forms a low resistance connection to and between gate electrode **27** and substrate **11**. In some embodiments, second internal conductor structure **913** includes a trench **39** extending from major surface **28** into substrate **11**. Similar to transistor **30**, trench **39** is lined with insulating layer **41** and further includes a conductive trench contact **43** configured to provide an ohmic contact to substrate **11**. In some embodiments, second internal conductor structure **913** is electrically connected to a source electrode **472** with a second conductor **373**, which extends through the underlying insulative layer **31** and forms an electrical connection to trench contact **43**. In this configuration, second internal conductor structure **913** forms a source region with a portion of substrate **11** for MOSFET **920**. Further in this configuration, first internal conductor structure **911** forms a drain of MOSFET **920** with another portion of substrate **11**. Additionally, first internal conductor structure **911** is configured to function as at least a portion of the source of HEMT device **910**. Thus, in accordance with the present embodiment, the source of HEMT device **910** and the drain of MOSFET **920** are connected together as illustrated in FIG. **4**. Second internal conductor structure **913** forms an electrical connection between the source of MOSFET **920** and a source conductor electrode **472** formed on the surface of device **90**. In some embodiments, source electrode conductor **472** also connects to gate electrode **27** of HEMT device **910**. This forms an electrical connection between the HEMT gate and the MOSFET source as illustrated in FIG. **4**.

A doped region **921** is formed in substrate **11** in a region between the source and drain of MOSFET **920** to form a channel region of MOSFET **920**. Doped region **921** has a doping type that has opposite conductivity to that of substrate **11**. In some embodiments, doped region **921** is p-type and has a dopant concentration configured to form a channel under a selected gate bias. An internal gate structure **916** of MOSFET **920** is formed adjoining doped region **921**. In some embodiments, internal gate structure **916** has a similar structure to first and second internal conductor structures **911** and **913**. In some embodiments, internal gate structure **916** includes a trench **39** lined with insulating layer **41** and having a trench conductor **43**. One difference is that internal gate structure **916** includes gate dielectric layer **926** separating trench conductor **43** from doped region **921**. In some embodiments, gate dielectric layer **926** is silicon oxide or other gate materials used in MOSFET devices. In some embodiments, gate dielectric layer **926** is thinner than insulating layer **41**. In one embodiment, a portion **81** of insulating layer **31** on major surface **28** on the surface near the HEMT gate is extended to cover another end of the trench conductor **43** in internal gate structure **916**. In some embodiments, electrical contact is made to trench conductor **43** in internal gate structure **916** in another portion of device **90** (not shown).

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FIG. 9 illustrates an enlarged cross-sectional view of an embodiment of a multi-transistor device **100** that is an alternate embodiment of device **90** illustrated in FIG. 8. Device **100** is similar to device **90** but has a different conductivity type of MOSFET **930**. In some embodiments, substrate **11** in device **100** includes a p-type substrate instead of the N-type substrate of device **90**. In some embodiments, a portion of substrate **11** below internal gate structure **916** functions as the channel region of the MOSFET. Device **100** also includes a first doped region **927** of an opposite conductivity type (opposite to the substrate type, for example, n-type) formed in the substrate to function as the source region of MOSFET **930**. Another doped region **923** of the opposite conductivity type to substrate **11** is formed to function as the drain of MOSFET **930** and the source of HEMT device **910**. The gate of the MOSFET is formed as a gate structure similar to the gate structure of device **90** except that the gate structure adjoins a channel region of the substrate instead of a channel region formed by a doped region formed in the substrate. In some embodiments, first conductor **372** is isolated from gate electrode **27** by insulative layer **31** in first internal conductor structure **911**.

From all of the foregoing, those skilled in the art can determine that according to one embodiment, a method of forming a semiconductor device can comprise providing a base substrate of a first semiconductor material (for example, element **11**) wherein the base substrate defines a first current carrying electrode of the semiconductor device; forming III-nitride channel layer (for example, element **19**) on the base substrate; forming a III-nitride barrier layer (for example, element **21**) on the channel layer; forming a second current carrying electrode of the semiconductor device in the barrier layer; forming a gate (for example, element **27**) of the semiconductor device overlying a portion of the barrier layer and spaced apart from the second current carrying electrode; and forming a first internal conductor structure (for example, element **38**) extending from the barrier layer through the channel layer to the base substrate wherein the internal connector structure forms a low resistance vertical electrical current path from the base substrate to the barrier layer.

In another embodiment, the method can include forming the internal conductor structure to electrically connect to the base substrate and to the barrier layer.

A further embodiment of the method can include forming a first conductor within the barrier layer and forming a second conductor extending from the first conductor to the base substrate and forming an insulator between the second conductor and the channel layer.

In another embodiment, the method can include forming a Schottky barrier connection between the first conductor and the barrier layer.

In another embodiment, the method can include forming the internal conductor structure to electrically connect to the base substrate and to a major surface of the barrier layer.

In a further embodiment, the method can include forming a first doped region of a first conductivity type in the base substrate and spaced apart from the first internal conductor structure wherein the first conductivity type is opposite to a conductivity type of the base substrate; forming a gate conductor of a MOS transistor overlying the first doped region wherein a portion of the first doped region forms a channel region of the MOS transistor; forming a second internal conductor structure adjacent to but spaced apart from the first doped region, the second internal conductor structure extending from the barrier layer through the channel layer to the base substrate wherein the internal connector structure forms a low resistance electrical current path.

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Another embodiment of the method can include forming a first current carrying electrode of the MOS transistor as a portion of the base substrate underlying the first internal conductor structure.

In another embodiment, the method can also forming an electrical path between the gate and the second internal conductor structure to form a low resistance electrical connection from the gate to the base substrate wherein a portion of the base substrate underlying the second internal conductor structure forms a first current carrying electrode of the MOS transistor.

Another embodiment of the method can include forming a first doped region of a first conductivity type in the base substrate and abutting the first internal conductor structure wherein the first conductivity type is opposite to a conductivity type of the base substrate and wherein the first doped region forms a first current carrying electrode of an MOS transistor; forming a second doped region of the first conductivity type in the base substrate and spaced apart from the first doped region wherein the second doped region forms a second current carrying electrode of the MOS transistor; forming a gate conductor of the MOS transistor overlying a portion of the base substrate that is between the first and second doped regions wherein the portion of the base substrate forms a channel region of an MOS transistor; forming a second internal conductor structure extending from the barrier layer through the channel layer to the second doped region wherein the internal connector structure forms a low resistance electrical current path.

In another embodiment, the method can also include forming an electrical path between the gate and the second internal conductor structure to form a low resistance electrical connection from the gate to the second current carrying electrode of the MOS transistor.

Those skilled in the art will also appreciate that another embodiment of a semiconductor device can comprise a semiconductor substrate (for example, element **11**) of a first conductivity type, wherein the semiconductor substrate provides a first current carrying electrode of the semiconductor device; a plurality of III-nitride layers (for example, elements **16**, **17**, **19**, **21**) on the semiconductor substrate to provide an HEM structure; and an internal conductor structure (for example, element **38**) extending from a major surface (for example, element **28**) of the HEM structure to the semiconductor substrate providing a vertical current path from the semiconductor substrate to the HEM structure.

Another embodiment can include an epitaxial layer between the conductive substrate and the plurality of III-nitride layers, wherein the epitaxial layer is of the first conductivity type and has a lower dopant concentration than the semiconductor substrate.

In another embodiment, the internal conductor structure includes a dielectric liner along a trench sidewall, which has an opening at the bottom of the trench; a trench filling, using a highly conductive layer, making contact to the conductive substrate and to a 2DEG region of the HEM device; and a first current carrying contact adjoining a back surface of the semiconductor substrate and in electrical communication with the trench filling.

In a further embodiment, the plurality of III-nitride layers includes a GaN channel layer and an AlGaIn barrier layer on the GaN channel layer to provide the 2DEG region. In other embodiments, the semiconductor device can further include a second current carrying contact in the AlGaIn barrier layer; and a gate structure overlying a portion of the AlGaIn barrier layer and spaced apart from the second current carrying electrode, and wherein the internal connector structure forms a

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low resistance electrical current path from the semiconductor substrate to the AlGaIn barrier layer.

Those skilled in the art will further appreciate that another embodiment of a semiconductor device can be a base substrate (for example, element 11) of a first semiconductor material wherein the base substrate forms a first current carrying electrode of the semiconductor device; a heterostructure (for example, element 13) comprising a III-nitride channel layer (for example, element 19) over the base substrate and a III-nitride barrier layer (for example, element 21) over the channel layer; a second current carrying electrode of the semiconductor device in the barrier layer (for example, element 36, 37); a gate (for example, element 27) of the semiconductor device overlying a portion of the barrier layer and spaced apart from the second current carrying electrode; and a first internal conductor structure (for example, element 38) extending from the barrier layer through the channel to the base substrate wherein the internal connector structure forms a low resistance electrical current path from the base substrate to the barrier layer.

In one embodiment, the first internal conductor structure electrically connects to the base substrate and to the barrier layer. In another embodiment, the first internal conductor structure is within the barrier layer and further comprises a second conductor extending from the first conductor to the base substrate, and wherein the second conductor is insulated from the channel layer. In other embodiments, the heterostructure comprises an AlGaIn buffer layer on the base substrate; a GaN channel layer on the AlGaIn buffer region; and an AlGaIn barrier layer on the GaN channel layer.

In a further embodiment, the semiconductor device further comprises a first doped region of a first conductivity type in the base substrate and spaced apart from the first internal conductor structure wherein the first conductivity type is opposite to a conductivity type of the base substrate; a gate conductor of an MOS transistor overlying the first doped region wherein a portion of the first doped region forms a channel region of the MOS transistor; and a second internal conductor structure adjacent to but spaced apart from the first doped region, the second internal conductor structure extending from the barrier layer through the channel layer to the base substrate, wherein the internal connector structure forms a low resistance electrical current path.

In an alternative embodiment, the semiconductor device further comprises a first doped region of a first conductivity type in the base substrate and abutting the first internal conductor structure wherein the first conductivity type is opposite to a conductivity type of the base substrate and wherein the first doped region forms a first current carrying electrode of an MOS transistor;

a second doped region of the first conductivity type in the base substrate and spaced apart from the first doped region wherein the second doped region forms a second current carrying electrode of the MOS transistor; a gate conductor of the MOS transistor overlying a portion of the base substrate that is between the first and second doped regions wherein the portion of the base substrate forms a channel region of an MOS transistor; and a second internal conductor structure extending from the barrier layer through the channel layer to the second doped region wherein the internal connector structure forms a low resistance electrical current path.

In other embodiments, an enhancement region is included in the base substrate adjoining the second internal conductor. In one embodiment, the enhancement region is a doped silicide region.

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In summary, a method for forming an HEM device and a structure therefore has been described. A highly doped base semiconductor substrate provides one current carrying electrode for the HEM device. A heterostructure is provided on the base semiconductor substrate and includes a III-nitride channel layer and a III-nitride barrier layer on the channel layer. A second current carrying electrode is situated in proximity to the barrier layer and, in some embodiments, a gate structure is provided in spaced relationship with the barrier layer. The structure includes at least one internal conductor structure that provides a vertical current path between the second current carrying electrode and the base substrate. Among other things, the method and structure provide for the routing source and gate conductive lines on the top surface of the structure with the drain conductive layer on the back surface of the die. In some embodiments, both the source and gate terminals are biased at low voltage, which puts a lower stress on inter-metal dielectric structures. This lower stress reduces electro-migration issues. The structure also provides for semiconductor chip area savings of at least 30% because bonding to the source and gate terminals can be done over the active area of the device. Additionally, the configuration facilitates the assembly of the HEM devices with other devices such as silicon MOSFET devices, which reduces parasitic inductances and resistances.

While the subject matter of the descriptions are described with specific preferred embodiments and example embodiments, the foregoing drawings and descriptions thereof depict only typical and exemplary embodiments of the subject matter and are not therefore to be considered to be limiting of its scope, it is evident that many alternatives and variations will be apparent to those skilled in the art.

As the claims hereinafter reflect, inventive aspects can lie in less than all features of a single foregoing disclosed embodiment. Thus, the hereinafter expressed claims are hereby expressly incorporated into this Detailed Description of the Drawings, with each claim standing on its own as a separate embodiment of an invention. Furthermore, while some embodiments described herein include some but not other features included in other embodiments, combinations of features of different embodiments are meant to be within the scope of the invention, and form different embodiments, as would be understood by those skilled in the art.

We claim:

1. A method of forming a semiconductor device comprising:

providing a base substrate of a first semiconductor material, wherein the base substrate defines a first current carrying electrode of the semiconductor device;

forming a III-nitride channel layer over the base substrate;

forming a III-nitride barrier layer over the channel layer;

forming a second current carrying electrode of the semiconductor device in the barrier layer;

forming a gate of the semiconductor device overlying a portion of the barrier layer and spaced apart from the second current carrying electrode; and

forming a first internal conductor structure extending from the barrier layer through the channel layer to the base substrate comprising a first conductor within the barrier layer, a second conductor extending from the first conductor to the base substrate and an insulator between the second conductor and the channel layer, wherein the first internal conductor structure forms a low resistance vertical electrical current path from the base substrate to the barrier layer.

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2. The method of claim 1, wherein forming the first internal conductor structure includes forming the internal conductor structure to electrically connect to the base substrate and to the barrier layer.

3. The method of claim 1, wherein:

forming the III-nitride channel layer comprises forming a GaN channel layer; and

forming the III-nitride barrier layer comprises forming an AlGaN barrier layer.

4. The method of claim 1, wherein forming the first conductor within the barrier layer includes forming a Schottky barrier connection between the first conductor and the barrier layer.

5. The method of claim 1, wherein forming the first internal conductor structure includes electrically connecting to the base substrate and to a major surface of the barrier layer.

6. The method of claim 1 further including forming a first doped region of a first conductivity type in the base substrate and spaced apart from the first internal conductor structure, wherein the first conductivity type is opposite to a conductivity type of the base substrate;

forming a gate conductor of a MOS transistor overlying the first doped region, wherein a portion of the first doped region forms a channel region of the MOS transistor; and forming a second internal conductor structure adjacent to but spaced apart from the first doped region, the second internal conductor structure extending from the III-nitride barrier layer through the III-nitride channel layer to the base substrate, wherein the second internal conductor structure forms a low resistance electrical current path.

7. The method of claim 6, wherein forming the first internal conductor structure includes forming a first current carrying electrode of the MOS transistor as a portion of the base substrate underlying the first internal conductor structure.

8. The method of claim 6 further including forming an electrical path between the gate and the second internal conductor structure to form a low resistance electrical connection from the gate to the base substrate, wherein a portion of the base substrate underlying the second internal conductor structure forms a first current carrying electrode of the MOS transistor.

9. The method of claim 1 further comprising:

forming a first doped region of a first conductivity type in the base substrate and abutting the first internal conductor structure, wherein the first conductivity type is opposite to a conductivity type of the base substrate, and wherein the first doped region forms a first current carrying electrode of a MOS transistor;

forming a second doped region of the first conductivity type in the base substrate and spaced apart from the first doped region, wherein the second doped region forms a second current carrying electrode of the MOS transistor; forming a gate conductor of the MOS transistor overlying a portion of the base substrate that is between the first and second doped regions, wherein the portion of the base substrate forms a channel region of the MOS transistor; and

forming a second internal conductor structure extending from the III-nitride barrier layer through the III-nitride channel layer to the second doped region, wherein the second internal conductor structure forms a low resistance electrical current path.

10. The method of claim 9 further including forming an electrical path between the gate and the second internal con-

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ductor structure to form a low resistance electrical connection from the gate to the second current carrying electrode of the MOS transistor.

11. A semiconductor device comprising: a base substrate of a first semiconductor material, wherein the base substrate forms a first current carrying electrode of the semiconductor device; a heterostructure comprising a III-nitride channel layer over the base substrate and a III-nitride barrier layer over the channel layer; a second current carrying electrode of the semiconductor device in the barrier layer; a gate of the semiconductor device overlying a portion of the barrier layer and spaced apart from the second current carrying electrode; and a first internal conductor structure extending from the barrier layer through the channel layer to the base substrate, wherein the first internal conductor comprises a first conductor within the barrier layer and a second conductor extending from the first conductor to the base substrate, and wherein the second conductor is insulated from at least the channel layer, and wherein the first internal conductor structure forms a low resistance electrical current path from the base substrate to the barrier layer.

12. The semiconductor device of claim 11, wherein the first internal conductor structure electrically connects to the base substrate and to the barrier layer.

13. The semiconductor device of claim 11, wherein side surfaces of the first conductor make electrical contact with at least the barrier layer.

14. The semiconductor device of claim 11, wherein the heterostructure comprises:

- a AlGaN buffer layer on the base substrate;
- a GaN channel layer on the AlGaN buffer region; and
- a AlGaN barrier layer on the GaN channel layer.

15. The semiconductor device of claim 11 further comprising:

- a first doped region of a first conductivity type in the base substrate and spaced apart from the first internal conductor structure, wherein the first conductivity type is opposite to a conductivity type of the base substrate;
- a gate conductor of a MOS transistor overlying the first doped region, wherein a portion of the first doped region forms a channel region of the MOS transistor; and
- a second internal conductor structure adjacent to but spaced apart from the first doped region, the second internal conductor structure extending from the barrier layer through the channel layer to the base substrate, wherein the second internal conductor structure forms a low resistance electrical current path.

16. The semiconductor device of claim 11 further comprising:

- a first doped region of a first conductivity type in the base substrate and abutting the first internal conductor structure, wherein the first conductivity type is opposite to a conductivity type of the base substrate, and wherein the first doped region forms a first current carrying electrode of an MOS transistor;
- a second doped region of the first conductivity type in the base substrate and spaced apart from the first doped region, wherein the second doped region forms a second current carrying electrode of the MOS transistor;
- a gate conductor of the MOS transistor overlying a portion of the base substrate that is between the first and second doped regions, wherein the portion of the base substrate forms a channel region of the MOS transistor; and
- a second internal conductor structure extending from the barrier layer through the channel layer to the second doped region, wherein the second internal conductor structure forms a low resistance electrical current path.

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17. A semiconductor device comprising: a base substrate of a first semiconductor material, wherein the base substrate forms a first current carrying electrode of the semiconductor device; a heterostructure comprising a III-nitride channel layer over the base substrate and a III-nitride barrier layer over the channel layer; a second current carrying electrode of the semiconductor device in the barrier layer; a gate of the semiconductor device overlying a portion of the barrier layer and spaced apart from the second current carrying electrode; and a first internal conductor structure extending from the barrier layer through the channel layer to the base substrate, wherein the first internal conductor comprises a first conductor within the barrier layer and a second conductor extending from the first conductor to the base substrate, and wherein the second conductor is insulated from at least the channel layer, and wherein the first conductor has a side surface in electrical contact with at least the III-nitride barrier layer, and wherein the first internal conductor structure forms a low resistance electrical current path from the base substrate to the barrier layer.

18. The semiconductor device of claim 17, wherein the side surface of the first conductor further makes electrical contact to at least a portion of the III-nitride channel layer.

19. The semiconductor device of claim 17 further comprising:

a first doped region of a first conductivity type in the base substrate and spaced apart from the first internal conductor structure, wherein the first conductivity type is opposite to a conductivity type of the base substrate;

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a gate conductor of a MOS transistor overlying the first doped region, wherein a portion of the first doped region forms a channel region of the MOS transistor; and
a second internal conductor structure adjacent to but spaced apart from the first doped region, the second internal conductor structure extending from the barrier layer through the channel layer to the base substrate, wherein the second internal conductor structure forms a low resistance electrical current path.

20. The semiconductor device of claim 17 further comprising:

a first doped region of a first conductivity type in the base substrate and abutting the first internal conductor structure, wherein the first conductivity type is opposite to a conductivity type of the base substrate, and wherein the first doped region forms a first current carrying electrode of an MOS transistor;

a second doped region of the first conductivity type in the base substrate and spaced apart from the first doped region, wherein the second doped region forms a second current carrying electrode of the MOS transistor;

a gate conductor of the MOS transistor overlying a portion of the base substrate that is between the first and second doped regions, wherein the portion of the base substrate forms a channel region of the MOS transistor; and

a second internal conductor structure extending from the barrier layer through the channel layer to the second doped region, wherein the second internal conductor structure forms a low resistance electrical current path.

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